HIGH-SPEED LOGARITHMIC PHOTODETECTORS WITH WIDE INPUT SIGNAL RANGE

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and B. M. Stepanov

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16. Abstract

A description is given of high-speed (passband > 20 MHz) logarithmic photodetectors with a large input signal range (up to 10^5). The methods and facilities of obtaining nonlinear luminous characteristics over a wide amplitude and time range are discussed. The results are presented of a study of the amplitude and time characteristics of photodetectors based on certain photomultipliers. The mechanism of nonlinear conversion of electron fluxes (conversion regulated by a space charge) is discussed.

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The methods of obtaining the logarithmic luminous characteristics of a photomultiplier by summation of signals from a series of multiplication stages are well known [1]. The nonlinear elements in the devices in question result in restriction of the frequency band of the passband of the device in the case of low input signals. /193*

Photodetectors based on photomultipliers mass produced by industry and having a frequency band of > 20 MHz in a dynamic input signal range of up to 10^5 are described in what follows. The photodetectors represent a photomultiplier the power supply divider of which permits regulation of the voltage in a number of final multiplication stages. The output signal is taken from a 75-ohm resistor inserted into the plate circuit connected to the final dynode.

With the photocathode of the photomultiplier illuminated by light pulses (ISSH-7 pulse lamp) of a duration of 10^{-7} sec at the level of 0.5 of the amplitude from 10^{-19} to 10^{-4} watt, a family of photomultiplier luminous characteristics was plotted at various voltages in the last multiplication stage.

There was then found in the last multiplication stage the voltage at which the widest possible dynamic input signal range is achieved and at which maximum approximation of the luminous to the logarithmic characteristic occurs. Similar measurements were also performed for the next to last multiplication stage, and so forth, the operating conditions of the photomultiplier being determined as a result.

The luminous characteristics obtained for a number of photomultipliers are presented in the drawing. The power supply divider, in particular that for the

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*Numbers in the margin indicate pagination in the foreign text.

FEU-59, consisted of resistances of the following values, starting from the zero power busbar: 0.15 R, 3.1 R, 1.5 R, R and the remainder in accordance with the standard circuit diagram, R = 180 kilohm.

As is to be seen from the characteristics cited, the dynamic input signal range (with an output range of 10^2) reaches as much as 10^5, with the luminous characteristic changing from linear to logarithmic as the input signal increases. In the dynamic range of 10^3 the luminous characteristic remains near the logarithmic, after which increase in the output signal ceases.

From the qualitative viewpoint the operation of the photodetectors as the input signal increases may be described as follows. With a linear luminous characteristic and one characterized by transition to the logarithmic the operation of the photodetector corresponds to the ordinary operation of a photomultiplier when a space charge is present [2].

After the formation of a space charge in the last space gap, the majority of the secondary electrons dislodged from the next-to-last dynode will return to this dynode. As the input signal increases, an increasingly large space charge will be formed in the region of the next-to-last dynode; owing to the influence of the latter a redistribution of the electrons between the next-to-last dynode and the collector will be effected, a redistribution that can be regulated by the value of the output current.

These conditions of nonlinear electron flux conversion will arise before a virtual cathode is formed in the space gap. The collector and the operation of the last multiplication stages are designed so that maximum weakening of the conditions of virtual cathode formation is achieved. This is accomplished in particular by utilizing a collector of pronounced reflector construction (gap between last dynode and anode), and by means of considerable increase in the voltage in the next-to-last multiplication stages in comparison to the voltage in the last stage. /194

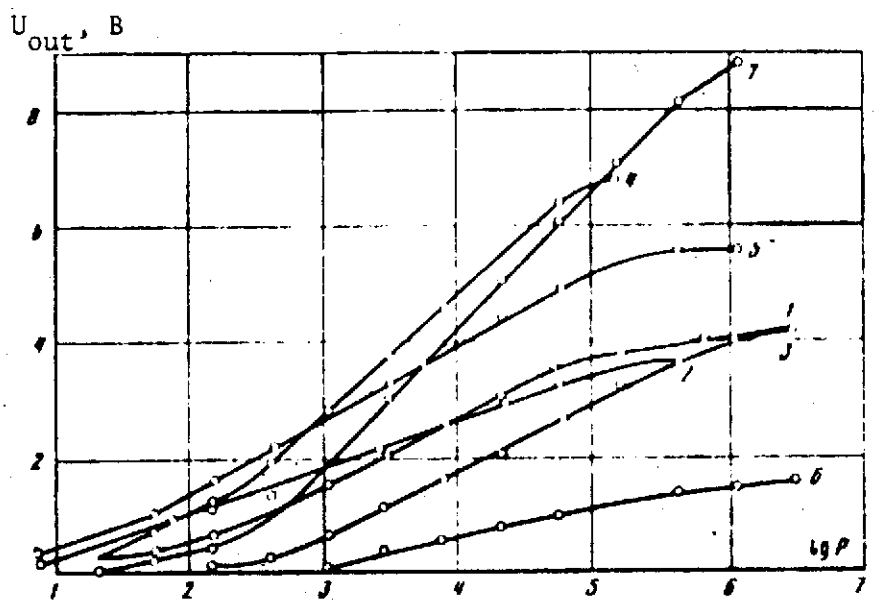
Let us consider the mechanism of logarithmic conversion of electron fluxes in a photomultiplier, representing the final space gap in the form of a diode operating under initial current conditions. After the formation of a space charge in the region of the next-to-last dynode the density of which will exceed

the density of the electrons at the collector, the next-to-last dynode may be regarded as a cathode emitting electrons of maximum energy determined by the voltage in the next-to-last multiplication stage.

If the distribution of the axial components of the velocities of the electrons entering the next-to-last – final dynode gap is Maxwellian, and the maximum energy of the flux electrons considerably exceeds the acceleration voltage value in the final space gap, the volt-ampere characteristic of the final space gap may, in accordance with the Boltzmann formula and the expression for the diode current, be expressed in the form

$$I_c = I_d e^{-U_c A}, \qquad (1)$$

in which I_c and I_d are the collector current and the current of the next-to-last dynode, U_c the dynamic voltage in the space gap, and A a coefficient allowing for the velocity of the electrons entering the gap.



Luminous Characteristics of Photodetectors With an Output Resistance of 75 Ohms. 1, FEU-11; 2, FEU-13B; 3, FEU-14B; 4, FEU-53; 5, FEU-59; 6, FEU-83; 7, FEU-93.

Taking the logarithm of (1) and replacing U_c with $R_1 I_c$, in which R_1 is the resistance of the collector load, we obtain

$$AR_1 I_c + \ln I_c = \ln I_d \qquad (2)$$

When the energy of the electrons entering the space gap considerably exceeds the voltage in the gap, and $I_c \gg 1$, with the value $\ln I_c$ in the left hand member of (2) ignored, the amplitude characteristic of the final space gap may be represented in the form

$$I_c \sim K \ln I_d,$$

in which K is a constant.

Thus by matching the initial potential distributions in the last multiplication stages in the photomultipliers with the grating system of multiplication it is possible to create high-speed photodetectors having a logarithmic amplitude characteristic over a wide dynamic range of input signals.

The time characteristics of the photodetectors were studied by analysis of the change in the inherent time resolution of the photomultipliers on change in the input signals over the entire dynamic luminous characteristic range. The results of the measurements demonstrated that the time resolution of the photodetectors remains unchanged and equal to the inherent time resolution of the photomultiplier virtually over the entire dynamic range of input signals. /195

The constant time resolution over a wide dynamic range of input signals makes it possible in solving problems relating to allowance for the effect of transients to represent the photodetectors in question as series-connected linear ones of a linear and inertialess device with corresponding dynamic range and time resolution values and a nonlinear amplitude characteristic. This in turn permits investigation of questions relating to the accuracy of dynamic measurements by the linear systems analysis method.

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